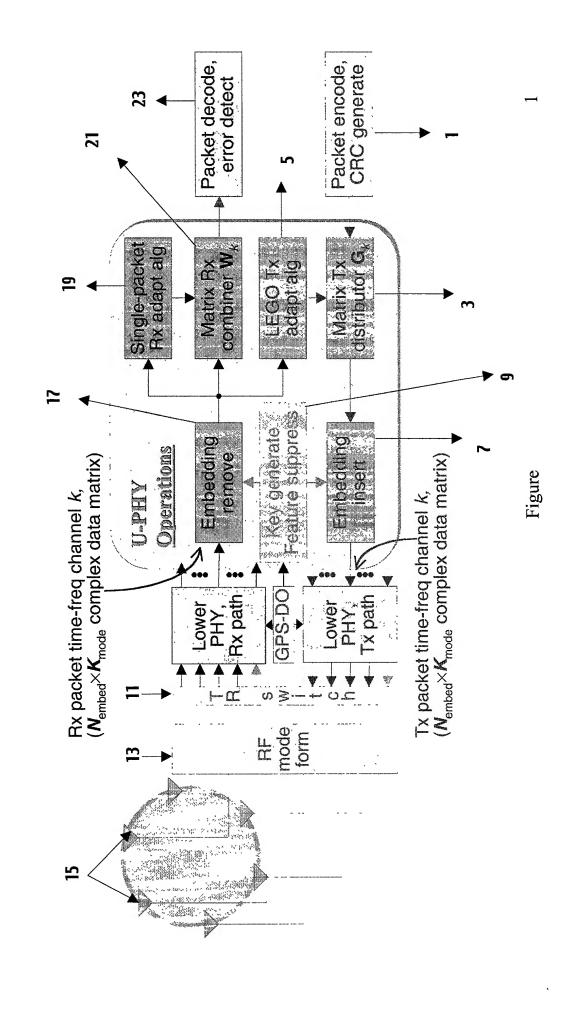
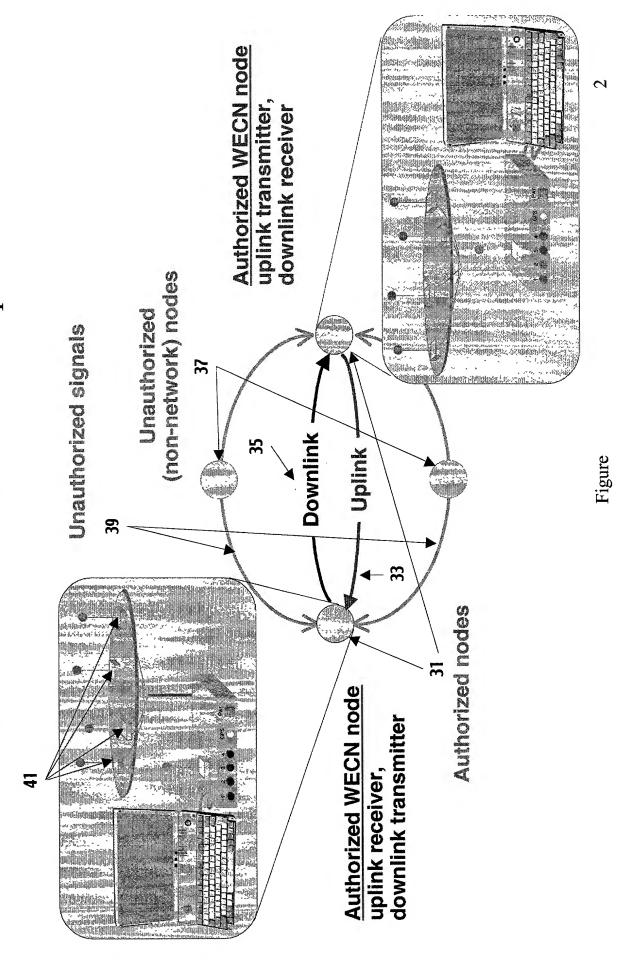
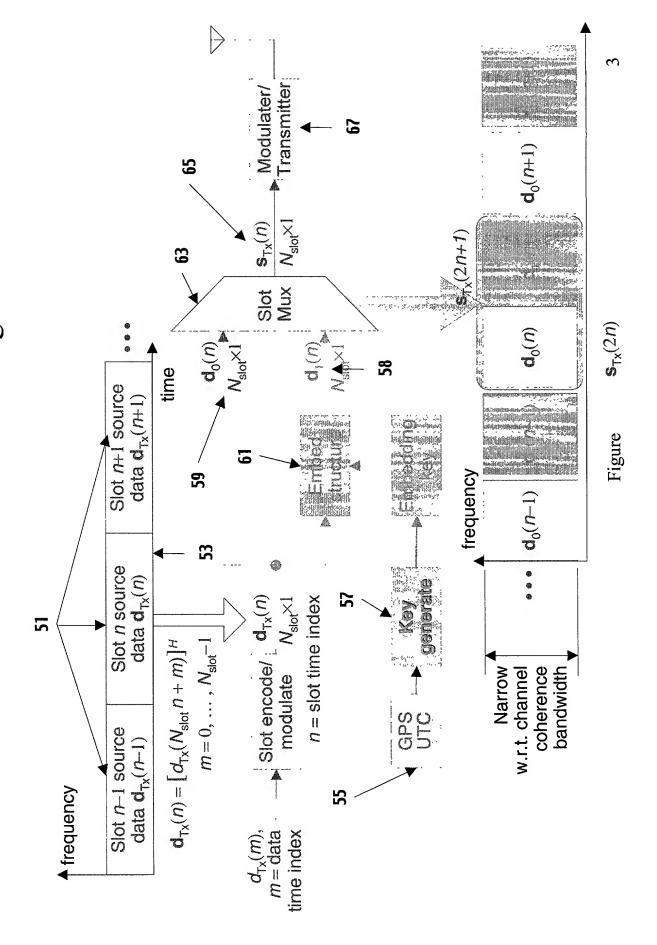
# WECN Structural Embedding/Removal



# WECN with external sources/recipients



### Time-Slot Embedding

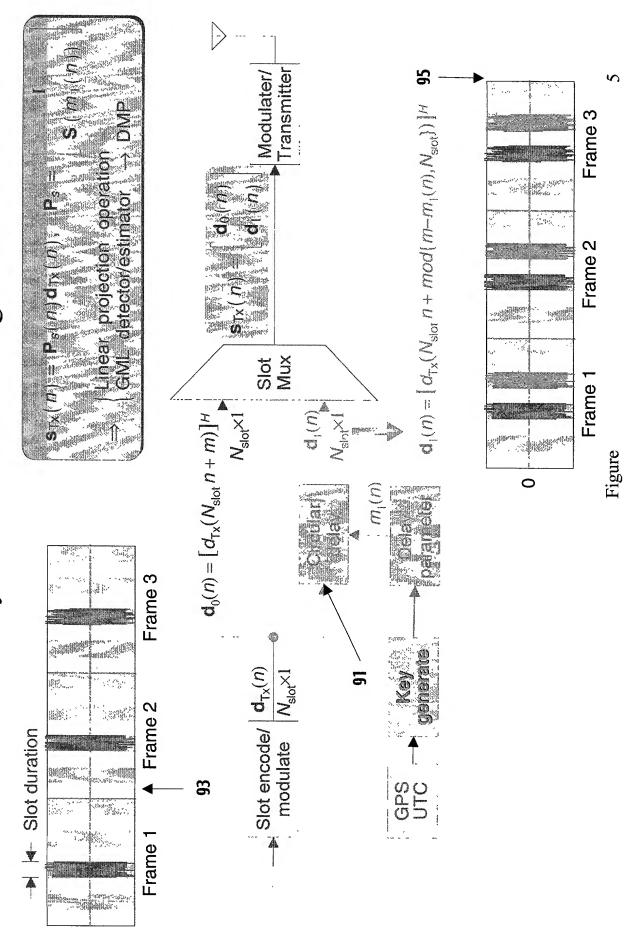


#### Narrow w.r.t. coherence BW over antenna array Slot n+1 estimated data $\mathbf{d}_{\mathrm{Dx}}(n+1)$ Slot decode/ demodulate 85 time 2 Slot n estimated data $\mathbf{d}_{\mathrm{Dx}}(n)$ Time-Slot Reception/Removal combine diversity Slot & X<sub>0</sub>(n) 8 N<sub>slot</sub>×M <sub>Px</sub> S Slot n-1 estimated data $\mathbf{d}_{\mathrm{Dx}}(\mathit{n}\text{-}1)$ frequency X<sub>FX</sub>(2n=1) $N_{\rm slot}$ $\times M_{\rm Rx}$ N<sub>slot</sub>XN/n<sub>x</sub> $\mathbf{X}_{\mathsf{Rx}}(2n)$ $\left\{ \begin{array}{c} \left\{ \mathbf{X}_{\mathsf{Fx}}(n) \right\} \\ N_{\mathsf{slot}} \times M_{\mathsf{Fx}} \end{array} \right\}$ Dmx 2 n = slot time index $\mathbf{X}_{\mathsf{Rx}}(n) = [\mathbf{X}_{\mathsf{Rx}}(N_{\mathsf{slot}} n + m)]^H$ frequency Bank

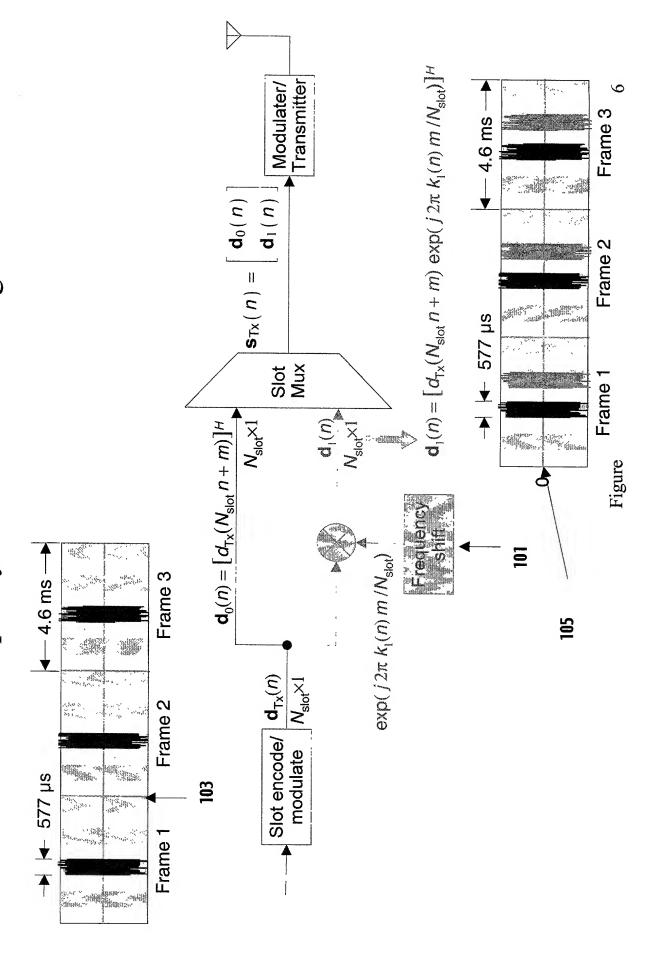
Figure

~

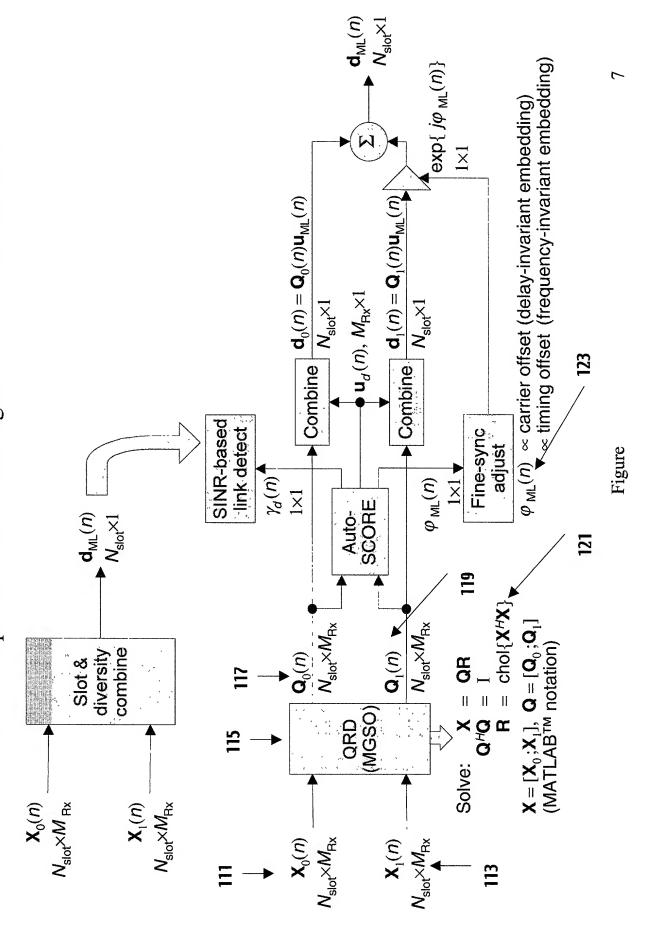
### Delay-Invariant Embedding



### Frequency-Invariant Embedding



Auto-SCORE Adaptation - Data whitehing & environmental evaluation



# Single-Link Auto-SCORE Algorithm - Software

Combine  $N_1 \times M$  matrices  $X_0$  and  $X_1$  into single  $2N \times M$  matrix X.

$$\mathbf{X} = [\mathbf{X}_0^H \ \mathbf{X}_1^H]^H$$

where  $N = N_{\text{slot}}$ ,  $M = M_{\text{Rx}}$  if time-slot embedding is employed at the transmitter. Compute **QR** decomposition of X,

$$X = QR$$

$$I = O_{H}$$

$$Q^H Q = I R = chol\{X^H X\},$$

where Q is defined by

$$\mathbf{Q} = [\mathbf{q}_1 \dots \mathbf{q}_M]$$
$$= [\mathbf{q}(1) \dots \mathbf{q}(N)]^H$$

Separate Q into  $N \times M$  submatrices  $Q_0$  and  $Q_1$ , such that

$$\mathbf{Y}_{0} = \mathbf{X}_{0}\mathbf{C}$$

$$\mathbf{Q}_0 = \mathbf{X}_0 \mathbf{C}$$
$$\mathbf{Q}_1 = \mathbf{X}_1 \mathbf{C},$$

where  $C = \mathbb{R}^{-1}$ . Form  $M \times M$  cross-correlation matrix S,

$$\mathbf{S} = (1/N) \mathbf{Q}_0^H \mathbf{Q}_1$$

Initialize whitened linear combiner weights

$$\mathbf{u} = [s(m,M)]$$

$$v = \|\mathbf{u}\| (L_2 \text{ norm})$$

$$\mathbf{u} \leftarrow \mathbf{u}/v$$

$$\|\mathbf{u}\|$$
 (L, nor

$$n \rightarrow n$$

Iteratively update combiner weights (preset iterations, or until stopping criterion met)

$$\mathbf{v} = \mathbf{S}\mathbf{u}$$

$$\rho = 1/2 \operatorname{sign} \{\mathbf{v}^H \mathbf{u}\}$$

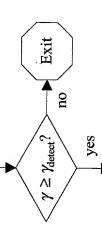
$$\mathbf{u} \leftarrow \rho \mathbf{v} + \rho^* \mathbf{S}^H \mathbf{u}$$

$$\mathbf{v} = ||\mathbf{u}|| (\mathbf{L}_2 \operatorname{norm})$$

$$= \|\mathbf{u}\| (L_2 \text{ norm})$$
  
 $\leftarrow \mathbf{u}/\mathbf{v}$ 

$$\gamma = \nu/(1-\nu)$$

Compute output SINR measurement  $\chi$ 



Compute phase-shift estimate  $\phi$ ,

$$\varphi = \arg\{\rho\}$$

Compute slot/diversity combined output data

$$= \mathbf{Q}_0 \mathbf{u} + (\mathbf{Q}_1 \mathbf{u}) e^{-j\varphi}$$

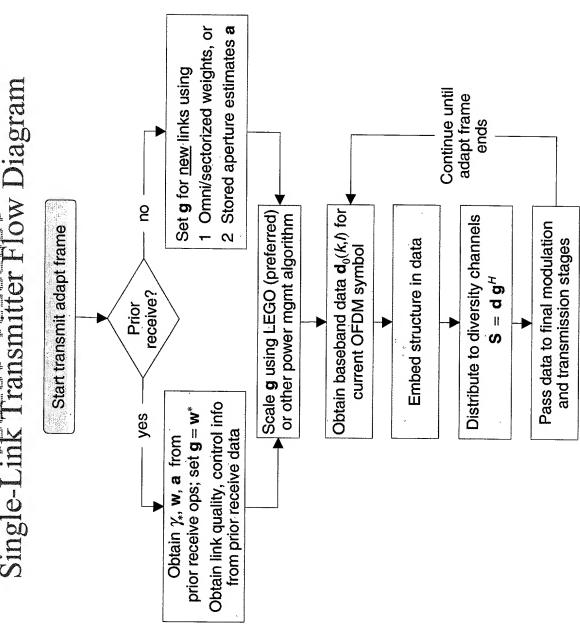
Compute unwhitened combiner weights w, aperture vector a,

$$w = Cu$$

$$\mathbf{a} = \mathbf{R}^H \mathbf{u}$$

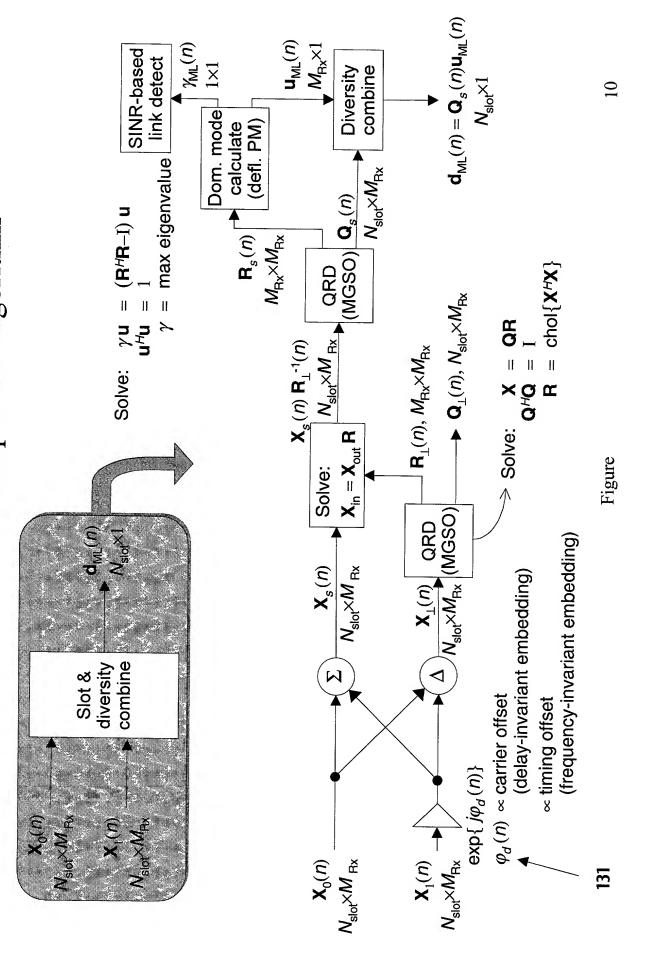
Figure

# Single-Link Transmitter Flow Diagram



Figure

# Alternative DMP Adaptation Algorithm



### alternative converging embedded-signal-differentiation algorithms

#### Dominant-Mode Prediction

 $\gamma \mathbf{u} = (\mathbf{R}^H \mathbf{R} - \mathbf{I}) \mathbf{u}$   $\|\mathbf{u}\| = 1 (\mathbf{L}_2 \text{ norm})$   $\gamma = \text{max eigenvalue}$ Solve:

#### **Optimization Algorithm**

Initialize:  $\mathbf{u} = r(M,M) [r^*(M,1) - 1]$   $\gamma = ||\mathbf{u}|| (L_2 \text{ norm})$ 

Iterate:

#### Auto-SCORE

Solve:

 $v(\varphi) \mathbf{u} = \mathbf{S}(\varphi) \mathbf{u}$   $\mathbf{S}(\varphi) = 1/2(\mathbf{S}\Theta^{i\varphi} + \mathbf{S}^H\Theta^{-j\varphi})$   $||\mathbf{u}|| = 1 \ (\mathbf{L}_2 \text{ norm})$ 

 $v(\phi) = \max \text{ eigenvalue}$ 

 $\varphi = \arg \max_{\varphi} \nu(\varphi)$ 

#### **Optimization Algorithm**

Initialize;

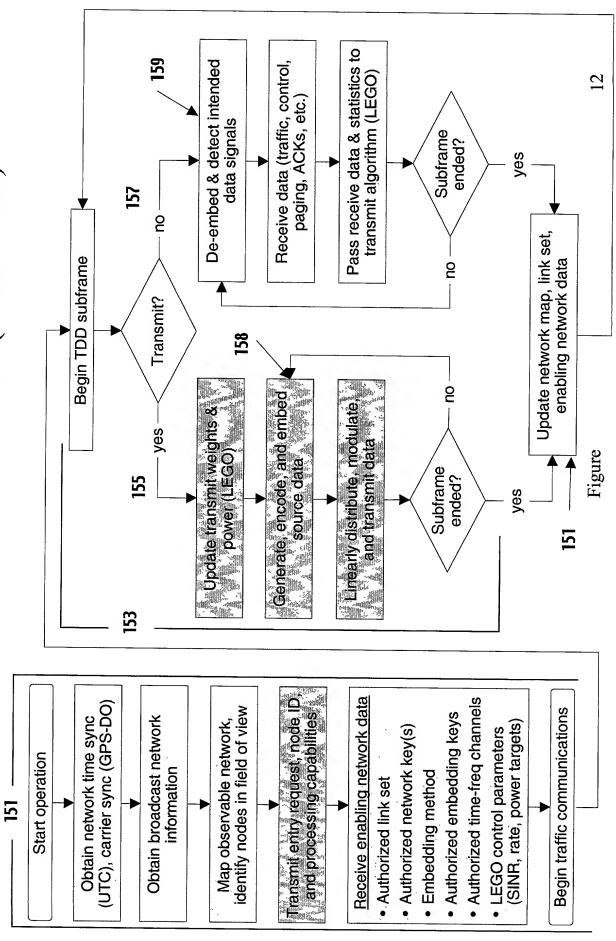
 $\mathbf{u} = [s(m, M)]$  $v = ||\mathbf{u}|| \ (L_2 \text{ norm})$ 

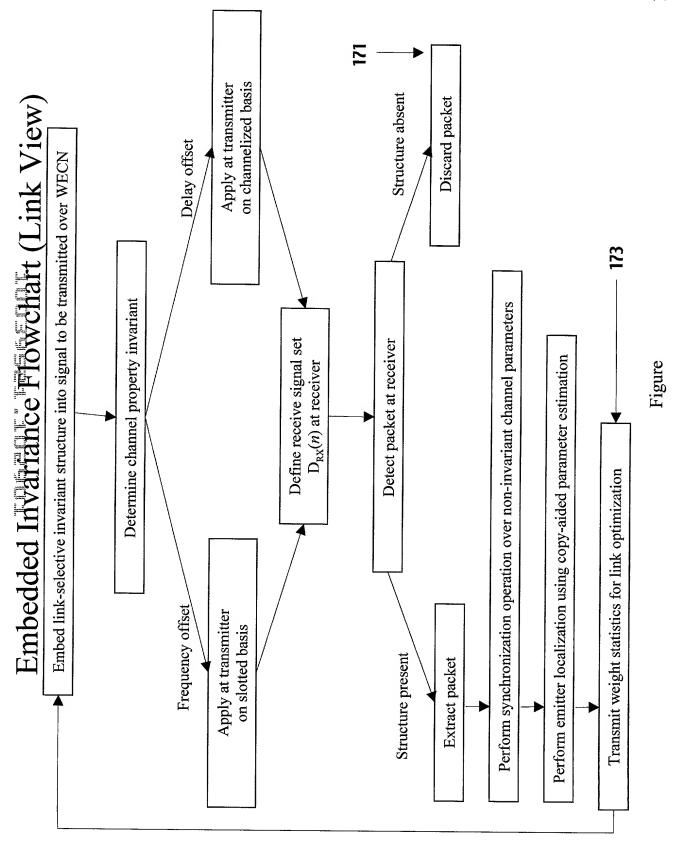
 $\rho = 1/2 \operatorname{sign}\{\mathbf{v}^H\mathbf{u}$ 

Finalize:

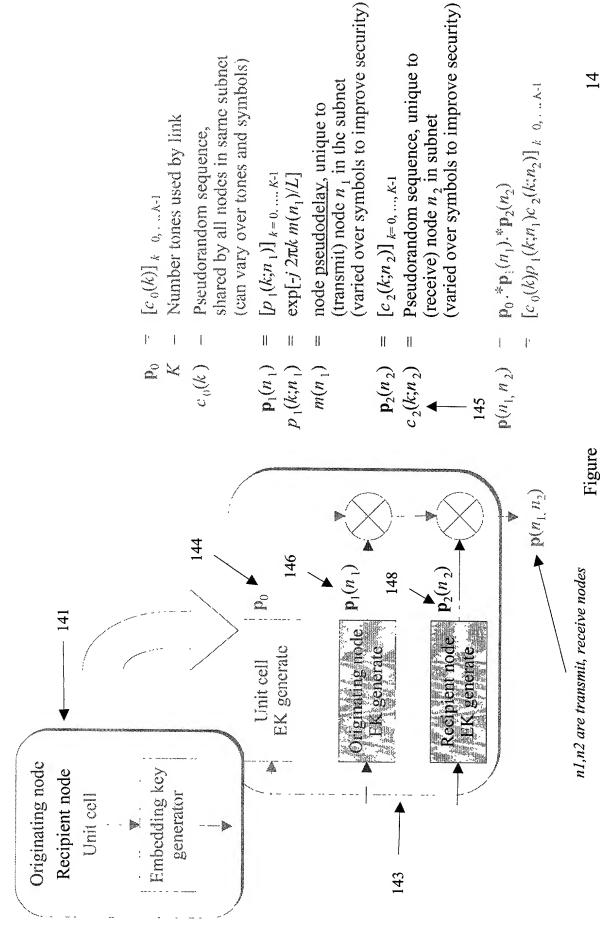
 $\gamma = \nu/(1-\nu)$ 

Embedded Invariance Flowchart (Nodal View)



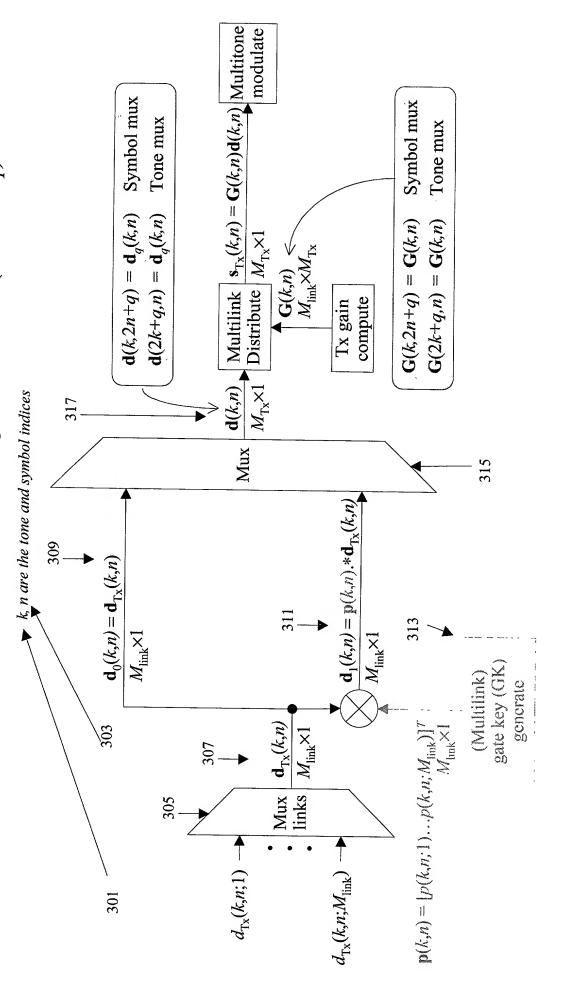


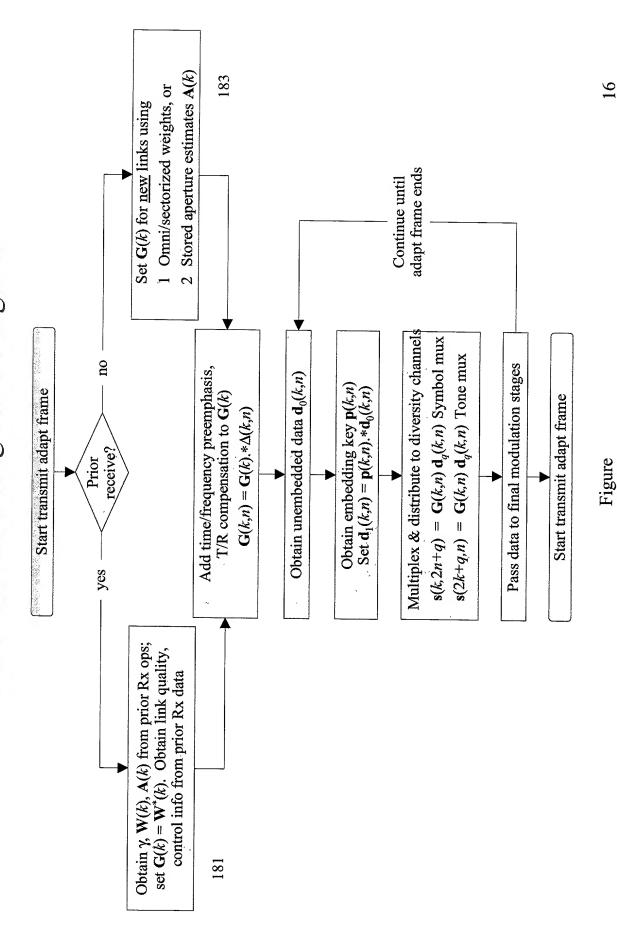
# Multilink Embedding Key Generation Algorithm



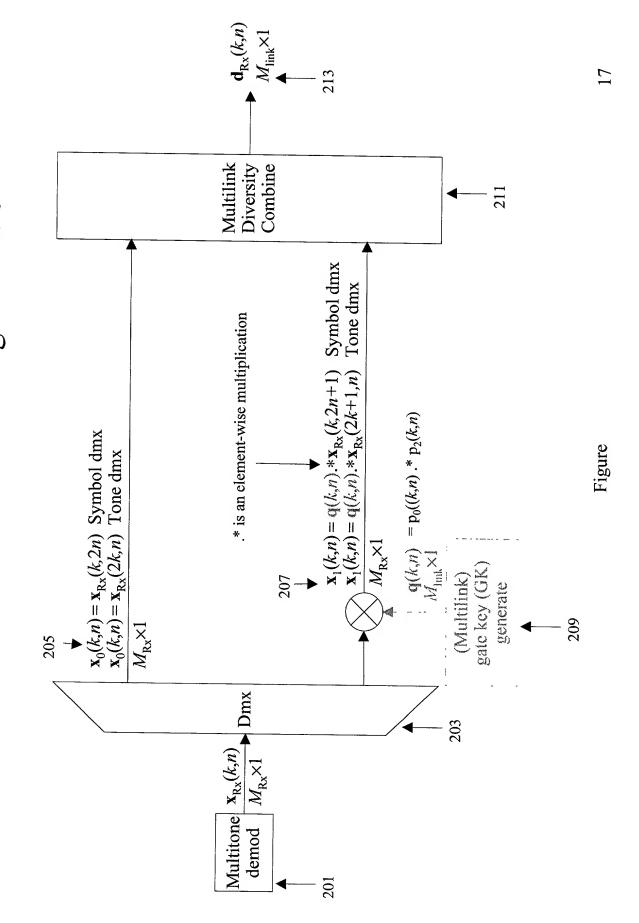
Figure

### Multilink Transmit Embedding Hardware (Node $n_1$ )





Multilink Receive Embedding Hardware 



### Multilink Receiver Flow Diagram

Start receive adapt frame

Obtain data from  $x_{Rx}(k,n)$  tone dmx of current OFDM symbol Obtain partial code  $\mathbf{q}(k,n) = [\mathbf{p}_0(k,n) \cdot * \mathbf{p}_1(k,n)]^*$ 

Demux  $\mathbf{x}_{Rx}(k,n)$  into  $\mathbf{x}_0(k,n)$  and  $\mathbf{x}_1(k,n)$ 

$$\mathbf{x}_0(k,n) = \mathbf{x}_{\mathrm{Rx}}(k,2n)$$
$$\mathbf{x}_0(k,n) = \mathbf{x}_{\mathrm{Rx}}(2k,n)$$

$$\mathbf{x}_1(k,n) = \mathbf{q}(k,n) \cdot *_{\mathbf{X}_{\mathbf{X}_{\mathbf{X}}}}(k,2n+1)$$
  $\mathbf{x}_1(k,n) = \mathbf{q}(k,n) \cdot *_{\mathbf{X}_{\mathbf{X}_{\mathbf{X}}}}(2k+1,n)$ 

= 
$$q(k,n) \cdot \mathbf{x}_{Rx}(k,2n+1)$$
 Symbol dmx  
=  $q(k,n) \cdot \mathbf{x}_{Rx}(2k+1,n)$  Tope dmx

Combine into submatrices  $X_0(n)$ ,  $X_1(n)$ 

$$\mathbf{X}_0(n) = [\mathbf{x}_0(1,n) \dots \mathbf{x}_0(K,n)]^H$$

$$\mathbf{X}_{1}(n) = [\mathbf{x}_{1}(1,n) \dots \dot{\mathbf{x}}_{1}(K,n)]^{H}$$

Combine  $K \times M$  matrices  $X_0(n)$  and  $X_1(n)$ , into single  $2K \times M$  matrix X,

$$\mathbf{X} = \left[ \mathbf{X}_0^H(n) \mathbf{X}_1^H(n) \right]^H$$

where  $N = N_{\text{stor}}$ ,  $M = M_{\text{Rx}}$  if time-slot embedding is employed at the transmitter.

Compute **QR** decomposition of X, X = QR

Separate **Q** into  $N \times M$  submatrices  $\mathbf{Q}_0$  and  $\mathbf{Q}_1$ , such that

$$\mathbf{Q}_0 = \mathbf{X}_0 \mathbf{C}$$

$$\mathbf{Q}_1 = \mathbf{X}_1 \mathbf{C},$$

where  $C = \mathbb{R}^{-1}$ . Form  $M \times M$  cross-correlation matrix S,

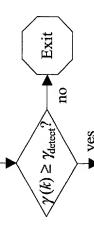
$$\mathbf{S} = (1/N) \mathbf{Q}_0^H \mathbf{Q}_1.$$

Continue until adapt frame Form  $M \times M$  cross-correlation matrix S(m),

over possible pseudodelays  $\tau(m)$ = $mT_{\text{sample}}$ .  $\mathbf{S} = \text{IFFT}_{K}\{\mathbf{q}_{0}(k)\,\mathbf{q}_{1}^{H}(k)\}$ 

Calculate modified auto-SCORE eigenvalues

 $\{\chi(m), \mathbf{u}(m), \varphi(m) \text{ over valid pseudodelays.}$ 



Compute:

Number received signals Qlink

Observed pseudodelays and phase shift

$$\mathbf{m}_* = [m_*(1) \dots m_*(Q_{\text{link}})]$$

$$\rho_* = \exp(i\phi(\mathbf{m}_*))$$

Combiner weights U

$$\mathbf{U}_* = \mathbf{U}(\mathbf{m}_*)$$

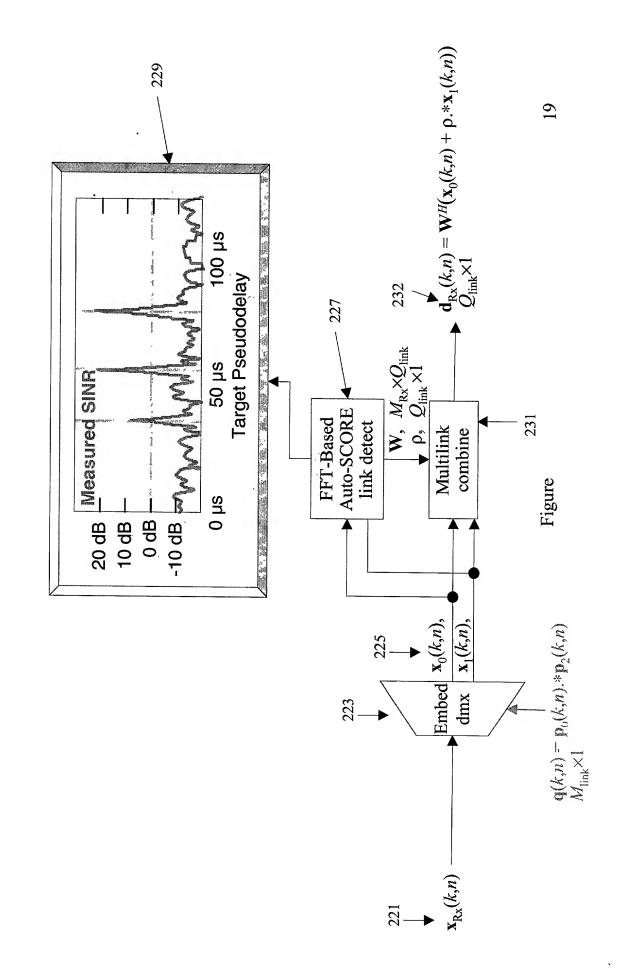
Estimate extraction SINR

$$\gamma_* = \gamma(\mathbf{m}_*)$$

 $\mathbf{D}_* = (\mathbf{Q}_0 + \mathbf{Q}_1 \operatorname{diag}\{\mathbf{p}_*\})\mathbf{U}_*$ Received data

Figure

Link Detection, Separation Operation



Pseudodelay Plots and Antenna Patterns

